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EVALUATION OF NEW MATERIALS FOR ROTOR HUB JOURNAL BEARINGS.(U)

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EVALUATION OF NEW MATERIALS FOR ROTOR HUB JOURNAL BEARINGS

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APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

The effort discussed herein is an accurate description of the results of comparative testing accomplished on new and existing journal bearing material concepts in order to obtain service life characteristics. Because bearing design was restricted to a particular envelope and the test load and motion conditions were groomed to accelerate wear, the reader should not judge particular materials as being inadequate for bearing applications due to the low service life demonstration. These tests only indicate that the bearing material was not suited for the given application. The results of this effort are expected to be used for reference purposes for any further investigation of nonlubricated journal bearings.

The project engineer for this effort was Mr. John W. Sobczak of the Aeronautical Technology Division.

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HELICOPTERS	SELF LUBRICATION	TEST AND EVALUATION
HUBS	LUBRICATION	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The nonlubricated bearing designs currently used in a number of helicopter rotor systems are based on a fabric-reinforced Teflon technology that is more than 10 years old. This test program was designed to evaluate some of the promising new self-lubricating materials and compare them to the present bearing design. These tests evaluated four new bearing materials plus two

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Item 20. Abstract (Continued)

standard fabric-reinforced Teflon bearings. Tests were conducted at normal flight loads and motions initially. The bearing loads were then increased in order to accelerate material deterioration and to reduce the required test time.

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INTRODUCTION

BACKGROUND

Field experience with the UH-1/AH-1 series helicopters with the 540 rotor system has shown that Teflon journal bearings are among the highest maintenance items on the aircraft. The current non-lubricated bearing design is based on a material technology that is more than 10 years old and is primarily based on the utilization of a fabric-reinforced Teflon material.

PURPOSE

This test program was designed to expand the material technology base for nonlubricated journal bearings by evaluating promising new bearing materials against different shaft materials. This program tested the bearings and shaft materials under normal flight loads and motions, which were incrementally increased in order to accelerate the wear of the bearings.

TECHNICAL DISCUSSION

The UH-1/AH-1 series helicopters with the 540 rotor system were selected as typical small helicopters that use nonlubricated bearings in the rotor hub. The test conditions selected for this program were therefore based on the AH-1 rotor blade feathering axis operating conditions.

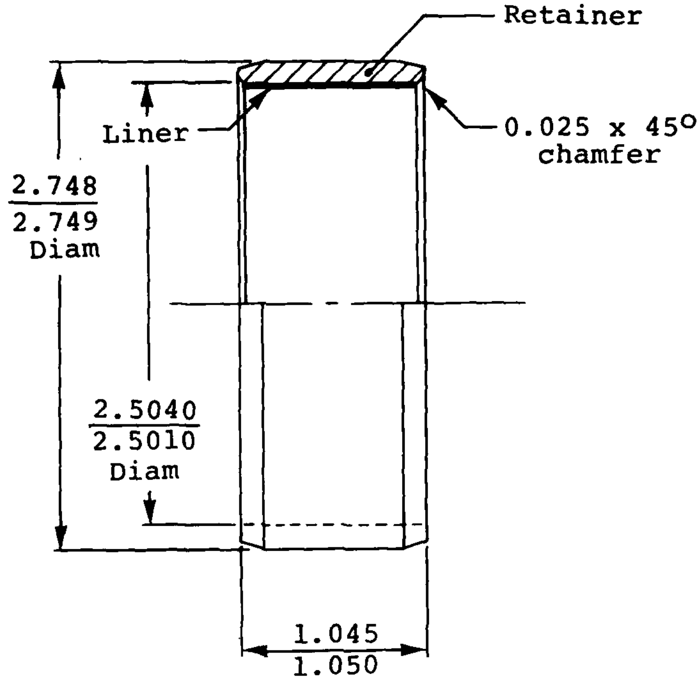
TEST BEARING SELECTION

The UH-1/AH-1 series helicopters use several different sizes of nonlubricated bearings in the rotor hub flapping and feathering axis, all of which are made to the same specification and by the same qualified source. The feathering bearings are the largest of these bearings and were not practical for use in this test program because of the high cost of fabricating test bearings of new materials in these large sizes. Also, the cost of rig hardware for the actual rotor hub bearings would have been significantly higher.

To reduce the cost of the test program, the smaller flapping bearing made to the same specification as the feathering bearings was selected as the test bearing. These bearings, Bell Helicopter P/N 540-011-110-11, were furnished by the Army for use as baseline bearings and were 2-1/2 inches long. Two test bearings, each 1 inch long, were made from each bearing. Figures 1 and 2 delineate the baseline bearing and the test bearings used in this program.

TEST OPERATING CONDITIONS

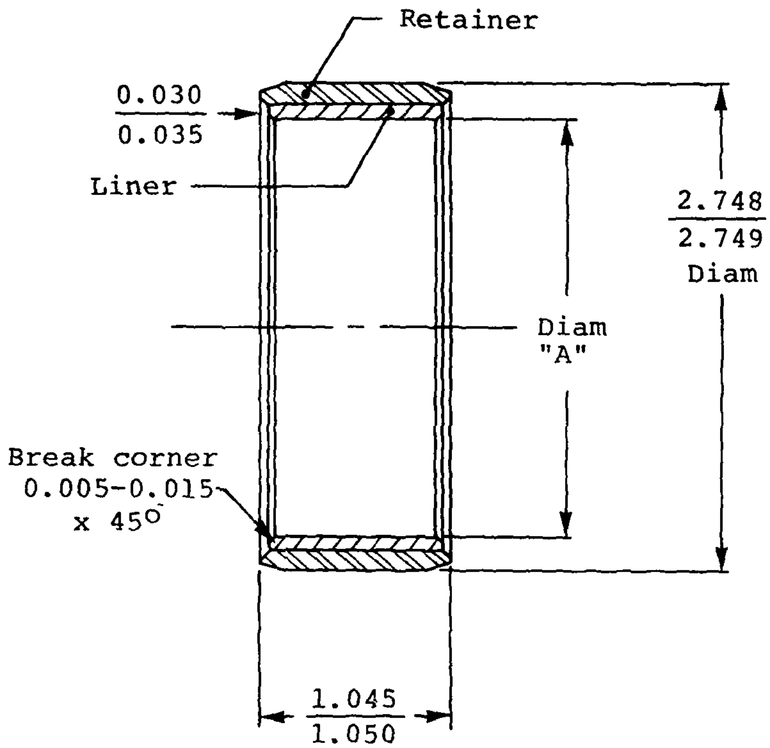
The typical operating cycle for the test bearings is given in Table 1. The maximum load on the bearings is about 3700 pounds or a unit load of 685 psi. For this test program, the initial test condition was selected to have approximately the same rubbing velocity and unit load as the maximum operating condition for the AH-1 helicopter.



Liner material is a Teflon fabric with a minimum gap of 0.030 inches.

NOTE: Dimensions in inches.

Figure 1. Baseline Test Bearing.



Liner Material	Diam "A"
Molalloy	2.504
Metaloplast	2.506
Torlon	2.509
Ryton	2.509

NOTE: Dimensions in inches.

Figure 2. New Material Test Bearing.

To achieve this, the oscillation angle was selected to be slightly greater than the maximum angle experienced by the bearing and the oscillation rate was increased to obtain the proper rubbing velocity. The radial load was reduced to obtain a slightly higher unit load than that carried by the rotor hub bearing. The actual test conditions run are listed in Table 2.

TABLE 1. TYPICAL OPERATING CYCLE, UH-1/AH-1 ROTOR HUB BEARINGS

Time (pct)	Oscillation (± deg)	Frequency (cpm)	Rubbing Velocity (a) (fpm)
14.5	3.2	324	10.9/12.8
32.0	5.7	324	19.4/22.8
22.0	7.0	324	23.9/28.0
22.5	8.2	324	28.0/32.8
9.0	9.5	324	32.4/38.0

(a) Lower number inboard bearing, higher number outboard bearing

TABLE 2. TEST SCHEDULE

Test Point	Oscillation (± deg)	Frequency (cpm)	Unit Load (a) (psi)	Test Hours
1	12	460	800	100
2	12	460	1600	100
3	12	460	2400	100
4	12	460	3200	100

(a) Unit load on center bearing

MATERIALS SELECTION

The promising bearing materials to be tested were selected from a large number of new materials that have been developed during the last 10 years. Because of the large number of materials available, one of the best materials from each of four different material types was selected in order to evaluate the widest range of materials. In selecting the material types to be evaluated, LFW-1 test results, manufacturers' data, and the current use of the material were used.

The following four material categories were selected:

Molalloy[1] - A proprietary material made by Pure Carbon that has been used very successfully in a number of high load spherical and journal bearing designs. This material is a metal-bonded molybdenum disulphide. This material had the lowest wear rate of all materials tested at 375 psi and 71 fpm on the LFW-1 material tester.

Torlon[2] - A proprietary material made by Amoco Chemicals Corp. that is used in a number of bearing applications. This material is a polyamide-imide with excellent physical and chemical properties up to 500°F. Two materials of this type ranked in the top six of all materials tested at 375 psi and 71 fpm on the LFW-1 tester.

Ryton[3] - A proprietary material made by Phillips Chemical that has excellent chemical resistance up to 400°F and excellent wear resistance at loads less than 1500 psi. This material is a polyphenylene sulfide and had the lowest wear rate of all materials tested at 375 psi and good wear at 750 psi and 71 fpm on the LFW-1 tester.

Metaloplast[4] - A proprietary material made by Pampus KG that is excellent for application in thin section bearings. This material is made by a special process that sinters a metallic screen into an abrasion-resistant tape. The wear rate of this material was very low below 1500 psi and 71 fpm on the LFW-1.

Table 3 contains the wear rates obtained on LFW-1 testers. The wear rate is expressed in inches of wear per inches rubbed times 10^{-9}.

Greek Ascoloy was selected as the material to be used for all test shafts. This is the same

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[1] Registered Trademark of Pure Carbon Company, Inc.

[2] Registered Trademark of Amoco Chemicals Corp.

[3] Registered Trademark of Phillips Chemical Co.

[4] Registered Trademark of Pampus Fluorplast, Inc.

material that the bearings rub against in the helicopter. The use of this material allowed a direct comparison of new material combinations with the types currently in use. Two test shaft coatings were selected to determine the effect of shaft material on bearing wear. One coating used was tungsten carbide LW-IN40 with MCAR100 epoxy seal. The other coating was Metco 136F chrome oxide, a plasma spray.

TABLE 3. LFW-1 WEAR RATES AT 71 FPM INCH/INCH x 10^{-9}

Material	Unit Load - psi					
	375	750	1500	2250	3000	3750
Torlon	2.54	3.57	2.92	4.96	5.31	5.12
Ryton	0.17	2.56	--	--	--	--
Molalloy	1.29	4.05	1.94	2.00	3.24	2.52
Metaloplast	1.29	1.88	--	--	--	--

TEST FACILITY

Two test stands of the type illustrated in Figure 3 were used for all testing. Each test stand contained two test heads of the type shown in Figure 4. Since each test head contains three test bearings, a total of twelve bearings could be run at one time.

The prime mover for each test stand was a 18.65 kW (25hp), 3600-rpm electric motor. Power was transmitted to a right angle gearbox with a 2:1 reduction ratio by a gear-belt drive. The 460-rpm output from the right angle gearbox was converted to oscillating motion by use of an eccentric drive and lever system driving a jackshaft. A test rig was driven from each end of the jackshaft by a flexible coupling. This arrangement was used to prevent drive system loads from being transmitted to the test bearings.

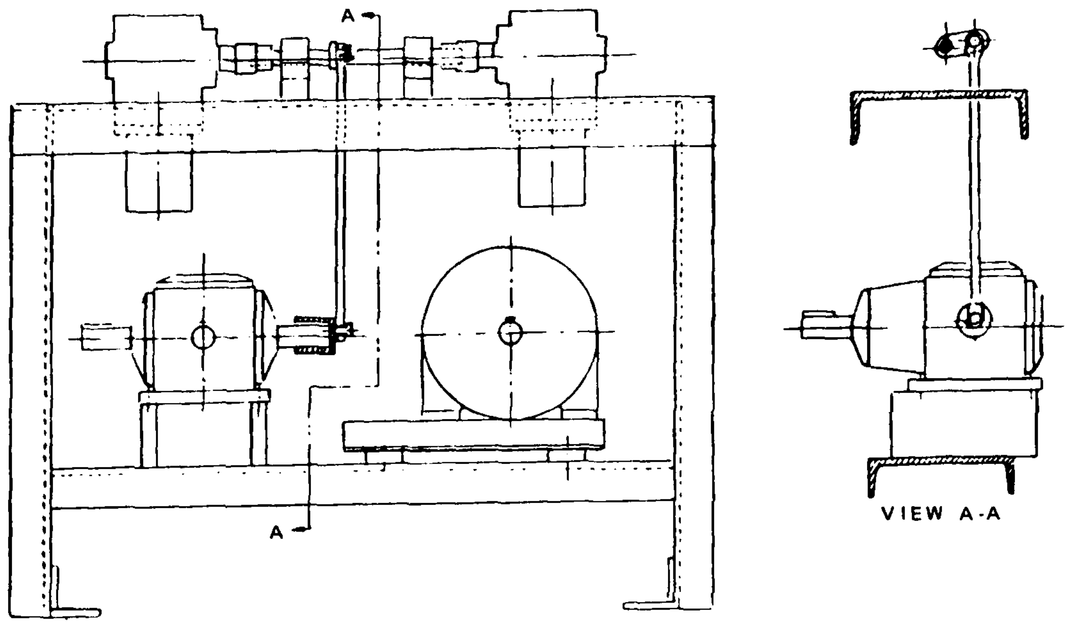

Figure 3. Schematic Drawing of Test Stand.

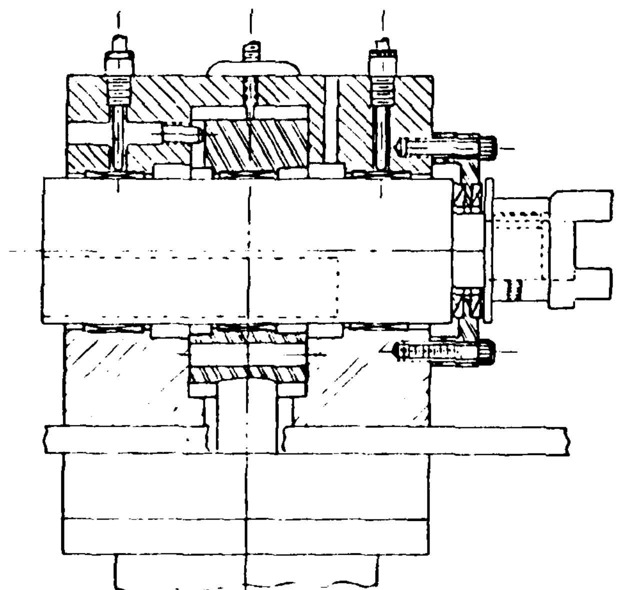

Figure 4. Cross Section Drawing of Test Head.

Each test rig contained three test bearings. The center bearing was installed in a housing unrestrained in the radial direction. The two end bearings were installed in the rigid outer housing. The radial load was applied to the center bearing by a hydraulic cylinder. This mounting arrangement caused the center bearing to carry twice as much load as either end bearing.

The outer case temperature of each bearing was monitored by a thermocouple. The thermocouple probes were held in contact with the outer case of the bearing by a coil spring. Temperatures were monitored on a continuous basis by a digital data recording system.

The pressure to the hydraulic cylinders was supplied by a recycling intensifier system. This system used regulated air pressure acting against a large piston to boost the oil pressure in a closed hydraulic system. The system was recycled about three times an hour, causing the hydraulic cylinder to recover any oil lost through seal leakage. During the recycling, the bearing load would decrease to zero for about 60 seconds and then return to the proper preset load.

TEST PROGRAM

The test program was conducted in two phases, screening and verification. The twelve screening tests were run on the material combinations identified in the test matrix (Table 4). This screening did not test all possible combinations but did test each bearing material against a minimum of two shaft materials and tested each shaft material against four bearing materials.

The verification test was to be a second test on the best material combinations. The best two bearing materials and the two best shaft materials were to be tested. Since none of the new bearing materials performed as well as the fabric-reinforced baseline bearings, the verification tests were changed to evaluate two different fabric-reinforced bearings.

TABLE 4. SCREENING TEST MATRIX			
	Shaft Surface Material		
Bearing Materials	Greek Ascolloy	Tungsten Carbide	Chrome Oxide
Fabric/Teflon	X	X	X
Torlon		X	X
Ryton	X		X
Molalloy	X	X	
Metaloplast	X	X	

The Table 2 test schedule was followed for both the screening and verification tests. Prior to starting a test and after each test point, the bearing inner diameter and shaft diameter were measured.

During the operation of the tests, the bearing outer ring temperature was monitored continuously by the digital data recording system. If the bearing temperature exceeded present limits, the drive motor was shut down. Each test point was scheduled to be run without interruption, but due to problems with the drive system, load system, and bearing overtemperature, tests were generally run in 10- to 20-hour increments.

Bearing wear was monitored during the test operation by using a depth micrometer. The distance between the top of the shaft and the top to the rig housing at each end of the rig was measured to determine wear of the end bearings. The distance between the top of the center bearing housing and the top of the rig housing was measured to determine wear of the center bearing. These measurements gave an indication if a bearing was wearing excessively, but did not correlate closely with post-test measurements.

TEST RESULTS

SCREENING TESTS

The only bearing material to successfully complete Test Point 2 and start Test Point 3 was the standard fabric-reinforced Teflon. The second best bearing material was the Molalloy, which completed Test Point 1 twice, but failed early during Test Point 2. A summary of the screening tests is contained in Table 5.

TABLE 5. RESULTS OF SCREENING TESTS

Rank	Bearing Material	Shaft Surface Material	Test Hours	Wear (in.)
1	Fabric/ Teflon	Chrome Oxide	200.5	0.0096
2	Fabric/ Teflon	Greek Ascolloy	200.5	0.0124
3	Fabric- Teflon	Tungsten Carbide	108.6	0.0100
4	Molalloy	Greek Ascolloy	99.1	0.0016
5	Molalloy	Tungsten Carbide	102.9	0.0024
6	Molalloy	Greek Ascolloy	90.9	Broken
7	Metaloplast	Tungsten Carbide	21.9	0.0151
8	Metaloplast	Greek Ascolloy	21.9	0.0438
9	Ryton	Greek Ascolloy	0.9	0.0210
10	Torlon	Chrome Oxide	1.3	0.0606
11	Torlon	Tungsten Carbide	0.9	Worn Thru
12	Ryton	Chrome Oxide	0.8	Worn Thru

FABRIC-REINFORCED TEFLON

The fabric-reinforced Teflon bearings performed about equally well against the chrome oxide coated shaft and the uncoated Greek Ascolloy shaft. Both tests were stopped after a half hour at Test Point 3. The bearing wear when operating against the chrome oxide coated shaft was slightly lower than the wear obtained against the uncoated shaft. The test against the tungsten carbide coated shaft was terminated after only 8.6 hours at Test Point 2.

MOLALLOY

The first two tests with the Molalloy bearings were started using bearings with a diametral clearance of 0.002 inch. Testing against both the uncoated Greek Ascolloy and tungsten carbide coated shaft was interrupted after 1.1 hours because the bearings were being locked up by wear debris. The bearing bore was increased to obtain a diametral clearance of 0.0055 inch and the tests continued. These bearings completed the scheduled testing at the first test point, but five of the six bearings were cracked and testing was not continued.

To eliminate possible edge loading, a new set of Molalloy bearings were made that had a 3-degree lead-in angle. These bearings were run against a second uncoated Greek Ascolloy shaft. This test was stopped after 90.9 hours at Test Point 1 and the center bearing was found to be cracked and broken up on disassembly.

For the Molalloy to work in this application the bearing design would have to be optimized. The bearing design used for this program was limited to the same cross section as the fabric-reinforced Teflon bearings. If a heavier cross section had been used the Molalloy would have had less tendency to crack.

TORLON

The first two tests with this material against the chrome oxide and tungsten carbide coatings were terminated after only 0.9 hour because of excessive wear. This failure occurred much sooner than expected and an investigation was made into the processing procedure. The only potential deviation found was in the postcure of the material. A new set of liners was made and cured per the recommended procedure.

A second test was conducted against the chrome oxide coated shaft with the bearing wearing through in 1.3 hours instead of 0.9 hour.

RYTON

The first set of bearings had a nominal diametral clearance of 0.0055 inch and were tested against an uncoated Greek Ascolloy shaft and a chrome oxide coated shaft. The test was stopped after 15 minutes because of high wear. A second set of bearings was made up with the diametral clearance increased to 0.010 inch and tested against the same shafts as used in the first tests. This time the bearings ran 0.8 hour before the test was terminated for excessive wear.

METALOPLAST

This material was tested against an uncoated Greek Ascolloy shaft and a tungsten carbide coated shaft. The nominal diametral clearance was 0.007 inch. Both tests were terminated after 21.9 hours because the bearings had worn through.

Analysis of the screening test summary in Table 5 shows very little difference in the performance of the different shaft materials. Since no significant difference was found in the shaft materials, the uncoated Greek Ascolloy and the tungsten carbide coating were selected for verification tests.

VERIFICATION TESTS

These tests were run using two different fabric-reinforced Teflon bearings. Two sets (six bearings) were from the same lot used in the screening test. The other six bearings were made from production bearings that had never been installed in a housing. These tests were run to determine if any handling damage was being done to the surface of the bearings when they were being installed in a housing. When the first bearings were received it was noted that the bearing surface had a scuffed and rough appearance compared to a smooth polished surface of a new bearing that had never been installed in a housing.

Table 6 contains a summary of these tests.

TABLE 6. RESULTS OF VERIFICATION TESTS.

Rank	Bearing Material	Shaft Surface Material	Test Hours	Wear
1	New Teflon	Tungsten Carbide	189.4	Seized
2	Original Teflon	Greek Ascolloy	166.0	Seized
3	Original Teflon	Tungsten Carbide	165.6	Seized
4	New Teflon	Greek Ascolloy	131.5	Seized

BEARINGS REMOVED FROM HOUSINGS

The results compared closely with the results of the screening test; the test with the uncoated Greek Ascolloy shaft failed after 66 hours at Test Point 2. It completed 100 hours at Test Point 2 in the screening test. The test against the tungsten carbide coated shaft failed after 65.6 hours at Test Point 2, compared to 8.6 hours at Test Point 2 in the screening test. Based on the two tests, the uncoated shaft has a slightly better life than the tungsten carbide coated shaft, but this was not statistically significant.

NEW TEFLON BEARINGS

The bearings used in this test were obtained from the manufacturer prior to being assembled and bonded into a housing. The surfaces of these bearings were smoother than those of the bearings used in the other tests of the fabric-reinforced Teflon. The time to failure was approximately the same as with the original fabric-reinforced Teflon bearings. Against the unplated shaft, this bearing failed after 31.5 hours at Test Point 2, compared to 66 and 100 hours at Test Point 2 for the original bearings. When running against the tungsten carbide shaft, the new bearings failed after 89.4 hours at Test Point 2, compared to 8.6 and 65.6 hours at Test Point 2 for the original bearings.

CONCLUSIONS

Based on the results of these tests, the following conclusions have been reached:

1. None of the new materials evaluated performed as well as the current fabric-reinforced Teflon bearings when restricted to the same size envelope.

2. There was no significant variation in life among the fabric-reinforced bearings tested.

3. Surface texture of the fabric-reinforced bearings did not have a significant effect on the performance of the bearings.